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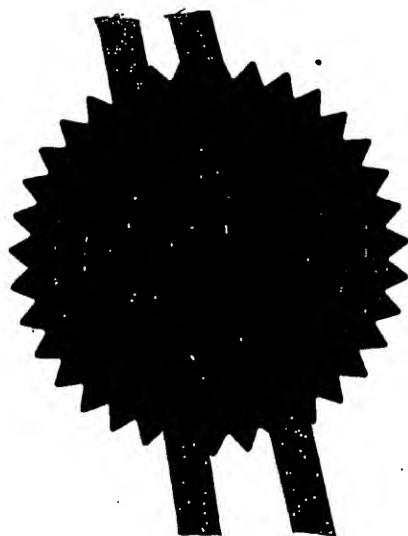
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30JUL02 E737057-1 003022  
P01/7700 0.00-0217564.4

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1. Your reference

PA0256

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3. Full name, address and postcode of the or of each applicant (underline all surnames)

AMERSHAM BIOSCIENCES UK LIMITED

 Amersham Place  
 Little Chalfont  
 Buckinghamshire  
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8331985001

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

TJ

4. Title of the invention

CELL RECORDING DEVICE

5. Name of your agent (if you have one)

HAMMER, Catriona, MacLeod; ROLLINS, Anthony, John and  
HAMMETT, Audrey, Grace, Campbell

"Address for service" in the United Kingdom  
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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if)

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Signature

HAMMER, Catriona, MacLeod

Date

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LIVINGSTONE, Helen  
01494 543390

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DUPLICATE

## CELL RECORDING DEVICE

## Field of the Invention

5 The present invention relates to devices of the type mentioned in the preambles of the independent claims for holding living cells for recording purposes.

## Prior Art

Studies of the electrophysiology of cells involve measuring the flow of ionic current across 10 the cell membrane inducing, or in response to, trans membrane conductance changes. One method of performing this involves holding a cell, penetrating the cell membrane with 1 or 2 microelectrodes and measuring the electrical signals detected by the microelectrode(s). A problem with such studies is that the cell-penetrating needles have been difficult to make and handle and that it has been difficult to hold the cell without harming it while inserting the 15 electrode. Japanese patent application 11-299496 describes a method for inserting a microelectrode into an oocyte in which an oocyte is positioned in or on a container which is provided with microelectrode guiding means. The microelectrode guiding means can be an elongated though hole which has a first end with a diameter greater than the diameter of the needle and an oocyte and a second end with a diameter which is less than the diameter of the 20 microelectrode and an oocyte. The oocyte is positioned in the through hole and then the microelectrode is introduced into the first end of the though hole and lowered until it penetrates the oocyte. In order to prevent breakage of the tip of the microelectrode, an microelectrode holder is proposed. This holder has a central bore into which a microelectrode can be loaded and is provided with an end face provided with protuberances which co- 25 operates with corresponding depressions in the face of the container surrounding the through hole in the container to align the central bore with the through hole. In use a microelectrode is partly introduced into the microelectrode holder, so that its fragile tip does not protrude from the microelectrode holder. An oocyte is placed in the container and then the microelectrode holder is fitted to container with the bore of the microelectrode holder aligned with the 30 through hole of the container. The microelectrode can then be pushed into the container and penetrate the oocyte while being guided by the walls of the container.

A problem with such a system is that it is time consuming as the oocyte has to be first captured, then placed in a container and then penetrated.

Summary of the Invention

5 The proposed device in accordance with the present invention comprises a penetrative, optionally, non-return, intracellular electrical access electrode assembly, optionally doped with a sealing compound to prevent ionic leakage. It improves over existing electrode designs in the public domain in that it permits electrode entry for multiple recording at points both inside and outside of cells. It is able to be used such that cells can be manipulated in arrays  
10 and brought into contact with electrodes in a controlled manner prior to an automatic gaining of intracellular access. The device is able to be fitted to industry-standard robots to enable large-scale drug profiling applications.

15 The advantages of this device are in the coupling of the initial cell holding step to the cell penetration step that gives full transmembranal electrical access. This may be achieved by making the cell membrane 'bow' inwards towards the electrodes only under seal conditions and this allows cell penetration by recessed electrode(s). Embodiments of the present invention may have multipoint conductor electrodes, penetrating barbs, independent electrodes and/or doped local lipolysis for access. Optionally, sealing compound to prevent  
20 ionic leakage may be used.

The use of penetrative electrodes on cells has been hampered by difficulties in holding individual cells in place prior to electrode insertion. The proposed device(s) get around this with the use of arrayable sheaths, which suck individual cells onto the aperture at the end of  
25 each sheath. The proximity event sensing / hold feature enables robust cell seeding and solution dipping methods to be used in different orientations (e.g. vertically with electrodes above the cell, vertically with the electrodes below the cell, inclined, etc.) and different experimental conditions.

30 According to the present invention, at least some of the problems with the prior art are solved by means of a device having the features present in the characterising part of claim 1 and methods in accordance with claims 7 and 8.

#### Brief Description of the Figures

Figure 1 shows schematically a first embodiment of an intracellular electrical access electrode in accordance with the present invention;

5 Figure 2 shows schematically a magnified view of the free end of the first embodiment of an electrode assembly in accordance with the present invention;

Figure 3 shows schematically a magnified view of the free end of a second embodiment of an electrode assembly in accordance with the present invention;

10

Figure 4 shows schematically a magnified view of the free end of a third embodiment of an electrode assembly in accordance with the present invention; and,

15

Figure 5 shows schematically a magnified view of a fourth embodiment of an electrode assembly in accordance with the present invention.

#### Detailed Description of Embodiments Illustrating the Invention

An electrode assembly in accordance with the present invention comprises a narrow bore sheath, preferably made of a bio-inert/biocompatible material, preferably mouldable and 20 machinable, such as a combination of rigid plastics, or the like, which are selected due to their insulating and low capacitance properties. The sheath is intended to protect one or more electrode needles mounted inside it and also to provide a tip against which a cell can be captured. Thus, inside the narrow bore there is at least one cell membrane-penetrating electrode needle (with two or more conducting portions electrically insulated from each other and the needle body) which can act as a multi-point access electrode, or there are two or more 25 cell membrane-penetrating electrode needles each of which have at least one conducting portion which can be used as an electrode or there are combinations of single-electrode needles and multi-electrode needles. The conducting portions can be variably connected to electrical supplies or recording preamplifiers according to specific applications. Insulating 30 elements or gaps between the conducting elements prevent short circuits between the conducting elements. Signals can also be sent down to, and/or received from, the cell via the sheath if it is itself conducting or if it is provided with one or more electrodes. Preferably, any change in conductance measured between electrodes near or at the sheath tip, due to the

presence of a cell near to the tip, can be sensed and then be used to initiate a small vacuum being applied through the sheath (using microprocessor-controlled syringes or other such suction devices), thus sucking the cell onto the tip of the sheath. Part of the cell may be sucked into the sheath by the suction and penetrated by the needle. The needle and/or the 5 suction may then hold the cell in place, which allows the cell and sensor assembly to be subsequently manipulated. The diameter and wall thickness of the sheath are chosen in order to prevent the cell being sucked completely into the sheath or alternatively, if the inner diameter of the sheath is greater than the diameter of the cell being captured, the interior of the sheath is provided with means to prevent the cell being sucked too far into the sheath.

10 Such means could be, for example, a flange projecting sufficiently far from the inner wall towards the centre of the sheath to prevent passage of the cell, and being provided with electrode needle or needles projecting out of it sufficiently far towards the open end of the sheath so as to ensure adequate penetration of a cell. The cell penetration needle is optionally coated with a non-conducting sealing compound (such as petroleum jelly) which prevents 15 ionic leakage from the cell. A voltage can be applied to some or all of the electrodes from an external stimulator and events may be recorded from some or all of the electrodes. Different electrodes connections can permit signal amplification for sensing voltage, current, metabolites, second messengers and/or provide reference signals to and/or from the cell and/or (if electrodes are placed suitably) from its surroundings.

20 Figure 1 shows schematically, and not to scale, a first embodiment of an intracellular electrical access electrode assembly 1 according to the present invention. Electrode assembly 1 comprises a hollow, elongated, tubular electrode sheath 3 which projects out of an electrode assembly body 5. Electrode assembly body 5 is intended to be gripped by an operator or

25 mounted on, or gripped by, a robot or to be attached to a movable carriage (not shown) in an automated analysis instrument and it can have any suitable shape. Preferably it is provided with docking features (not shown) such as specially shaped or positioned holes or projections which enable it to be accurately mounted on an automated manipulating device such as a robot arm or carriage or the like. An elongated electrode needle 7 is concentrically mounted 30 inside electrode sheath 3. One end 9 of electrode needle 7 is held in electrode body 5 and the other, free, end 11 of electrode needle 7 is positioned either level with the open tip 13 of electrode sheath 3 or, as shown in figure 1, inside the sheath 3 at a small distance d from the open, cell-contact end 13 of the sheath 3. Electrode needle 7 is provided with a plurality of

sensing electrodes 15a, 15b,...15n positioned near its free end 11. In this embodiment sensing electrodes 15a,15b,...15n are in the form of ring electrodes, preferably mounted flush with the surface of electrode needle 7 with the longitudinal axes of the ring electrodes concentric with the longitudinal axis of the electrode needle 7. A further electrode 15(n+1) is provided on the

5 exterior wall of electrode sheath 3. The electrode needle 7 and electrode sheath 3 may be made of insulating material and/or insulating material may be arranged on or in the electrode needle and electrode sheath in order to isolate the electrodes from each other. Electrode needle 7 can be provided with adjustable mounting means 29 (shown schematically) for displacing electrode needle 7 up or down in its longitudinal direction. Adjustable mounting

10 means may be used to move the free end of electrode needle 7 closer to or further away from the open end of electrode sheath 3 in order to vary the depth of penetration of the electrode needle into the cell that it is attached to. Alternatively, electrode needle 7 may be immovably mounted with its tip at a position chosen to ensure penetration of the cell being tested.

15 Other shapes of electrode are also possible as described below.

Each electrode 15a, 15b, ... 15n+1 is connected by a conductor 17a, 17b, ... 17n+1 to an input/output bus 19 of a computing and control device such as a personal computer 21. Computing and controlling device 21 is programmed to collect signals from electrodes 15a,

20 15b and to control a source of suction 23, such as a vacuum or suction pump or vacuum tank, connected via a suction line 25 to an opening 27 in electrode assembly body 5 which leads to the interior of electrode sheath 3. The source of suction 23 can be controlled to generate suction in electrode sheath 3.

25 Figure 2 shows an enlarged, schematic, part view of the free end of a first embodiment of an electrode assembly 1 in accordance with the present invention, with a cell 31 positioned on it. In this example, the cell is an oocyte cell with a diameter of approximately 1 mm. Such a cell can be captured on an electrode assembly in the following manner: the electrode assembly 1 is lowered into a bath containing a plurality of cells; as a cell passes in proximity to the open

30 end of electrode sheath 3, it causes a change in the conductance measured between electrode 15a and electrode 15n+1, and this change of conductance triggers computing and controlling device to operate the source of suction 23 such that a small vacuum occurs within electrode sheath 3, thereby sucking cell 31 onto the open, cell-contact end of the sheath. The bore of the

sheath is selected such that the cell 31 is too big to be sucked into the sheath but will be held on the end of the sheath by the negative pressure caused by the application of the vacuum. Suitable sheath bore diameters for 1 mm nominal diameter oocytes are in the range of 0.1-0.8 mm, preferably 0.3-0.6 mm. The dimension is chosen so that the vacuum pulls sufficient 5 cellular material into the sheath to permit electrode needle 7 to penetrate the cell membrane 33, and is therefore also dependent on how far the electrode needle 7 is from the sheath tip 13. Thus, the further the electrode needle 7 is from the sheath tip 13 then the greater the suction force and/or the width of the bore required to enable the cell 31 to be deformed enough to be penetrated. The shank of the electrode needle 7 can be of any suitable width e.g. a width up to 10 0.1 cell diameters and preferably electrode needle 7 tapers to a sharp narrow point. The width of the needle depends on the stiffness and brittleness of the material that it is made from, as well as the ease of forming the electrode and insulating regions on it. Glass electrodes may have a minimum width in the range of 0.01mm – 10 microns while less rigid materials such as plastics would usually require larger minimum widths. The maximum width of a needle 15 depends on the size of the cell being investigated and in general should not exceed 0.2 of a cell diameter in order to prevent the cell being killed by the needle penetration.

The penetration of the cell results in some electrodes, e.g. 15a, 15b being within the cell, and the remaining electrodes e.g. 15c, 15d,... 15n+1 being outside the cell. The penetration of the 20 electrodes is preferably adapted so that only some, e.g. two 15a, 15b, of the electrodes are inside the cell. The electrodes could be spaced at intervals corresponding to 0.1 of the diameter of the cell being investigated, e.g. at 0.1 mm intervals for electrodes intended to enter 1 mm diameter oocyte cells. In this way, when putting two electrodes inside the cell, the penetration of the cell is limited to less than half the cell diameter and the risk of accidentally

25 piercing the nucleus of the cell is reduced. If injection into the nucleus is intended than a longer needle may be used. The cell 31 may be positioned in a well 35 on an array containing a plurality of wells and the well 35 may contain a liquid 37 which prevents the cell from drying out. The liquid 37 can be dosed with chemicals and the response of the cell to the chemicals recorded via some or all of the electrodes 15a-15n+1.

30

Figure 3 shows an enlarged, schematic, part view of an electrode assembly in accordance with a second embodiment of the present invention in which the same reference numerals are used for features that it has in common with the first embodiment. In this embodiment the electrode

needle 7 is provided with a sharp tip 41 at its free end 11. This facilitates passage through the cell membrane. Since the cell membrane is an ionic insulator, physical penetration may cause non-specific ionic leakage which is minimised by the sharp tip 41. An optional cell-removal preventing device such as a barb device in the form of a tapered ring 43 which tapers down

5 towards the needle tip 41 may also be provided in order to resistant accidental removal of the electrode needle 7 from the cell 31, and leakage may be further minimised by applying non-ion-conducting sealing compound 45 (e.g. petroleum jelly) to the ring surface 47 which is intended to face the cell membrane 33 after the electrode needle 7 has been inserted in the cell, and/or to the surface of the needle which is intended to be in the region of the cell

10 membrane during use.

A schematic part view of a third embodiment of an electrode assembly in accordance with the present invention is shown in figure 4. This electrode assembly comprises a plurality of electrode needles 7a-7n arranged inside the electrode sheath 3. Each electrode needle 7a-7n is provided with its own tip electrode 15a-15n. Optionally each electrode needle may be provided with a further ring or spot electrode (not shown). Additionally, the individual electrode needles 7a-7n may optionally be joined together, or optionally surrounded by a strengthening tube 49 (shown by dashed lines), along at least a part of their lengths in order to strengthen them and prevent buckling of the individual electrode needles 7a-7n. Each electrode needle may be provided with an individual barb and/or surface provided with non-ion-conducting sealing compound or, as shown in figure 4, only the electrode needles 7a, 7b, intended to penetrate the cell membrane, are each provided with a barb 43 and sealing compound 45.

25 In use the electrode sheath is lowered over a container of cells. When a cell passes sufficiently close to the open end of the sheath such that the conductivity measured between the electrode needle tip electrode and the electrode on the electrode sheath varies, suction is applied to the electrode sheath and the cell sucked up against the end of the sheath. The electrode needle may then be either lowered such that it penetrates ('stings') the cell, or the portion of the cell 30 inside the sheath may be sucked up the sheath by increased suction until the cell membrane is pierced by the electrode needle inside the sheath. The degree of penetration can be made adjustable by providing a means for varying the lowering of the electrode needle or for

varying the suction pressure, for example, in order to avoid unwanted penetration of the cell nucleus.

Figure 5 shows schematically a further embodiment of the present invention. In this embodiment an intracellular electrical access electrode assembly 1 is provided in the base of a well 35. Well 33 may be one well of a number of wells, e.g. 96 well, 384 wells, etc. arranged in rows and columns or circles or spirals, or any other shape on a platter or other supporting substrate.

10 Intracellular electrical access electrode assembly 1 comprises a hollow tubular electrode sheath 3 which projects up into the well from the bottom of the well 35. Electrode sheath 3 is positioned in the centre of well 35 and the inner walls 51 of well 35 may be straight as shown which allows adequate space around the cell for drug administration, or they may slope inwards towards the bottom of the well to act as aligning surfaces for a cell-positioning device

15 53. Cell-positioning device (shown in dashed lines) 53 can be any suitable device such a manually or automatically operated pipette containing one or more cells, or a hopper containing one or more cells or the like. As cell-positioning device 53 is lowered, the end of it comes into contact with well wall 51 which guides it to a central position above electrode sheath 3. Once it has been lowered as far as it can go, cell 31 can be ejected from it by a

20 plunger 61 onto the open end of electrode sheath 3. An elongated electrode needle 7 is concentrically mounted inside electrode sheath 3. The dimensions of the sheath and needle are adapted to the average diameter of the cell being examined. The sheath should have a diameter small enough to prevent the cell being pulled into the sheath while at the same time the sheath should a diameter which is sufficiently large such that the contact area between the

25 sheath and cell is large enough to prevent damage to the cell. Preferably sheath 3 has a diameter between 0.2 and 0.8 of the average cell diameter. Electrode needle must be long enough to accommodate all the electrodes necessary for the experiment being carried out on the cell, while also being rigid enough to avoid being damage when penetrating the cell and when being manufactured and positioned in the well. Preferably electrode needle 7 is at least

30 1 cell diameter long and up to 0.1 cell diameters wide. One end 9 of electrode needle 7 is fixed to the well bottom and the other free end 11 of electrode needle 7 is positioned either level with the open end 13 of electrode sheath 3 or, as shown in figure 5, inside the sheath 3 at a small distance  $d$  from the open, cell-contact end 13 of the sheath 3, in order to allow sheath

3 to protect it from damage. Distance  $d$  can be adapted to the size of the cell being penetrated and, in order to prevent the cell from being deformed too much when bringing it into contact with the needle 7, it should not be too large. Preferably it is less than 0.3 of a cell diameter and is preferably more than 0.1 cell diameters. Electrode needle 7 is provided with a plurality of sensing electrodes 15a, 15b,...15n positioned near its proximal end 11. In this embodiment sensing electrodes 15a, 15b,...15n are in the form of ring electrodes, preferably mounted flush with the surface of electrode needle 7 with the longitudinal axes of the ring electrodes concentric with the longitudinal axis of the electrode needle 7. Preferably the distances between the electrodes are chosen so that two or more electrodes can be inside the cell and

5 one or more electrodes outside the cell being examined. In the case of an oocyte with a diameter of 1 mm, electrodes 15a-15n may each be 0.05- 0.1 mm long in the longitudinal direction of the needle and spaced at 0.1-0.2 mm intervals. A further electrode 15(n+1) is provided on the exterior wall of electrode sheath 3. The electrode needle 7 and electrode sheath 3 are either made of insulating material and/or insulating material is arranged on or in

10 the electrode needle and electrode sheath in order to isolate the electrodes from each other. Optionally, electrode needle 7 can be provided with adjustable mounting means (not shown) for displacing electrode needle 7 up or down in its longitudinal direction. These adjustable mounting means may be used to move the free end of electrode needle 7 closer to or further away from the open end of electrode sheath 3 in order to vary the depth of penetration of the

15 electrode needle into the cell that it is attached to. Each electrode 15a, 15b, ... 15n+1 is connected by a conductor 17a, 17b, ... 17n+1 to an input/output bus 19 of a computing and control device such as a personal computer 21. Computing and controlling device 21 is programmed to collect signals from electrodes 15a, 15b and to control an optional source of suction 23, such as a vacuum or suction pump or vacuum tank, connected via a suction line 25

20 to an opening 27 in well 35 which leads to the interior of electrode sheath 3. The source of suction 23 can be controlled to generate suction in electrode sheath 3 in order to hold cell 31 onto electrode needle 7. Alternatively, cell 31 may be retained on electrode needle 7 by a barb (not shown) or a lid (not shown) fitted over the top of well 35.

25

30 Single units or arrays of single units of cell holding electrode arrangements in accordance with the first to third embodiments of the present invention, or the like, could be arranged to penetrate and hold cells from above in order to perform a dipping procedure in a drug-free or drug-containing solution (e.g. a small quantity of drug may be contained in a micro-drop

spotted out on a hydrophobic membrane, the cell may be dipped into the micro-drop, its response to the drug recorded and then it may be dipped in a drug free solution and its response recorded). Alternatively, units in accordance with the present invention could form arrays and operate with solution-containing wells, each containing a cell, with sides that guide 5 the 'stinging' electrode(s) towards the cell.

Preferably, devices in accordance with the present invention are made integrally of moulded and/or machined plastic materials with subsequently attached metal electrodes.

- 10 While the present invention has been illustrated by examples of embodiments in which rigid needles carrying conducting portions pass through the cell membrane, it is also conceivable that a transmembranal hole may be introduced by a hollow needle-type mechanism or a lipolytic chemical treatment to form a non-selective ion conductance path (e.g. phospholipase doping, detergent doping). Extra conductor points in continuity with the intracellular solution
- 15 could be used. Hollow, open-ended, electrolyte-containing needles, e.g. glass capillary needles containing conducting fluid are also conceivable.

The above mentioned embodiments are intended to illustrate the present invention and are not intended to limit the scope of protection claimed by the following claims.

## Claims

1. Cell holding electrode arrangement comprising a hollow electrode sheath (3) open at a cell-contact tip (13) characterised in that said sheath (3) surrounds at least one elongated electrode needle (7) provided with a plurality of sensing electrodes (15a, 15b,... 15n), or said sheath (3) surrounds a plurality of elongated electrode needles (7a, 7b,...7n) each provided with at least one sensing electrode (15a, 15b,...15n).  
5
2. Cell holding electrode arrangement in accordance with claim 1 characterised the said needle(s) (7; 7a, 7b,... 7n) does not/do not extend beyond the cell-contact tip (13) of said sheath (3).  
10
3. Cell holding electrode arrangement in accordance with any of the previous claim characterised in that said needle or at least one of said needles is provided with a cell-removal preventing device (43).  
15
4. Cell holding electrode arrangement in accordance with any of the previous claim characterised in that said needle or at least one of said needles is provided with a non-ion-conducting sealing compound (45).  
20
5. Cell holding electrode arrangement in accordance with any of the previous claim characterised in that said sheath (3) is arranged inside a well (35).  
25
6. Cell holding electrode arrangement in accordance with any of claims 1-4 characterised in that said sheath (3) is arranged on an automated manipulating device.  
30
7. Method for positioning electrodes inside a cell characterised by the steps of: positioning a cell at the cell contact tip (13) of a cell holding electrode arrangement in accordance with any of the previous claims; and, applying a suction to said cell so that it is pulled onto the electrode needle(s).  
35
8. Method for positioning electrodes inside a cell characterised by the steps of: positioning a cell at the cell contact tip (13) of a cell holding electrode arrangement in accordance with any of claims 1-6; and, pushing said cell onto said electrode needle(s).  
40

**Abstract**

The present invention relate to methods and devices for holding a cell and positioning recording electrodes inside it.

5

**Fig 1**

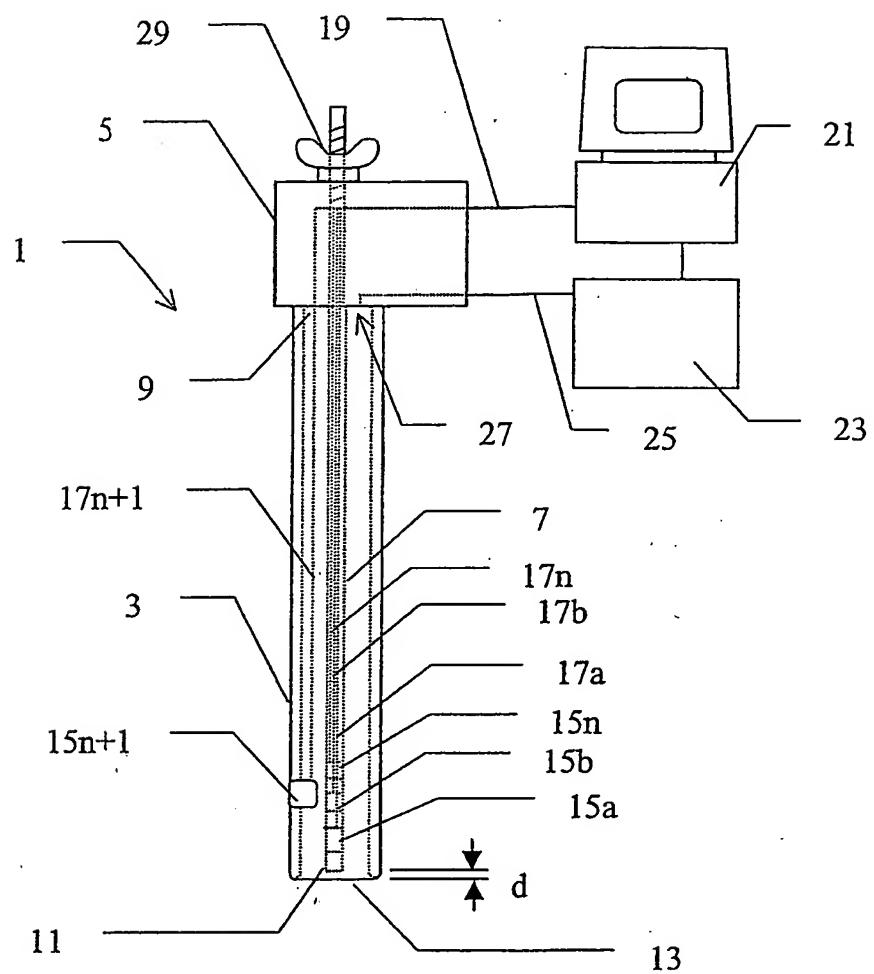


Fig. 1

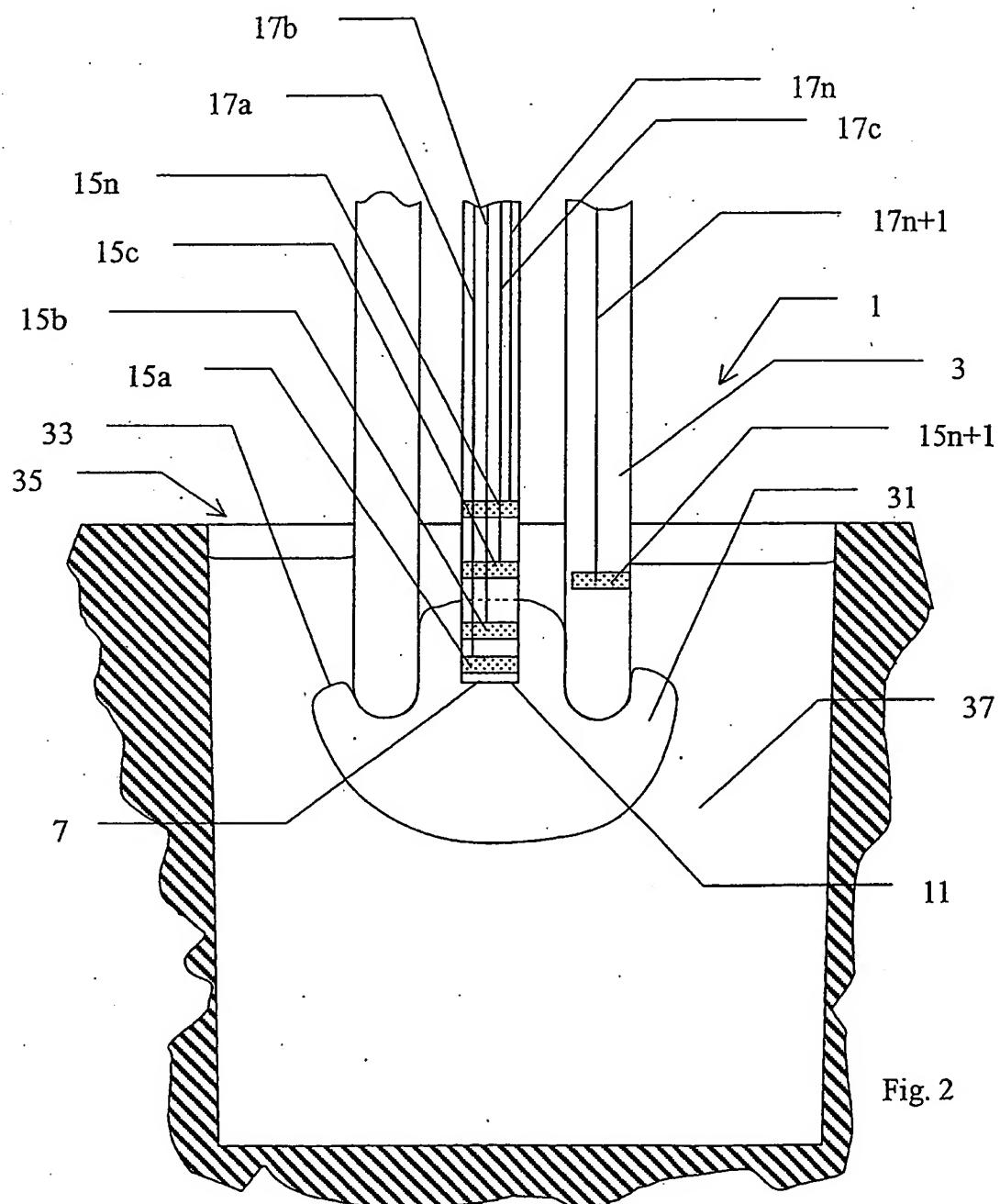


Fig. 2

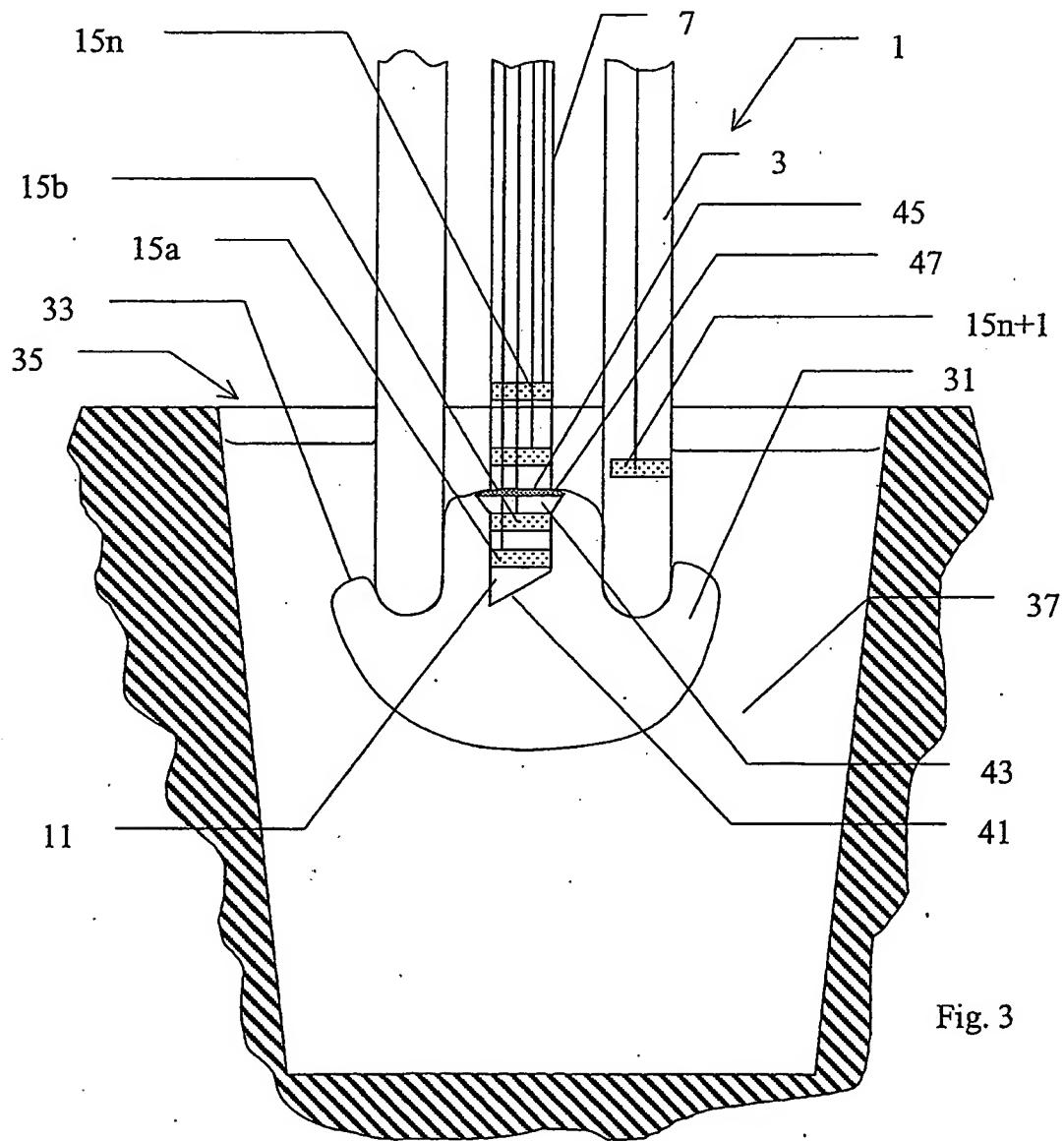


Fig. 3

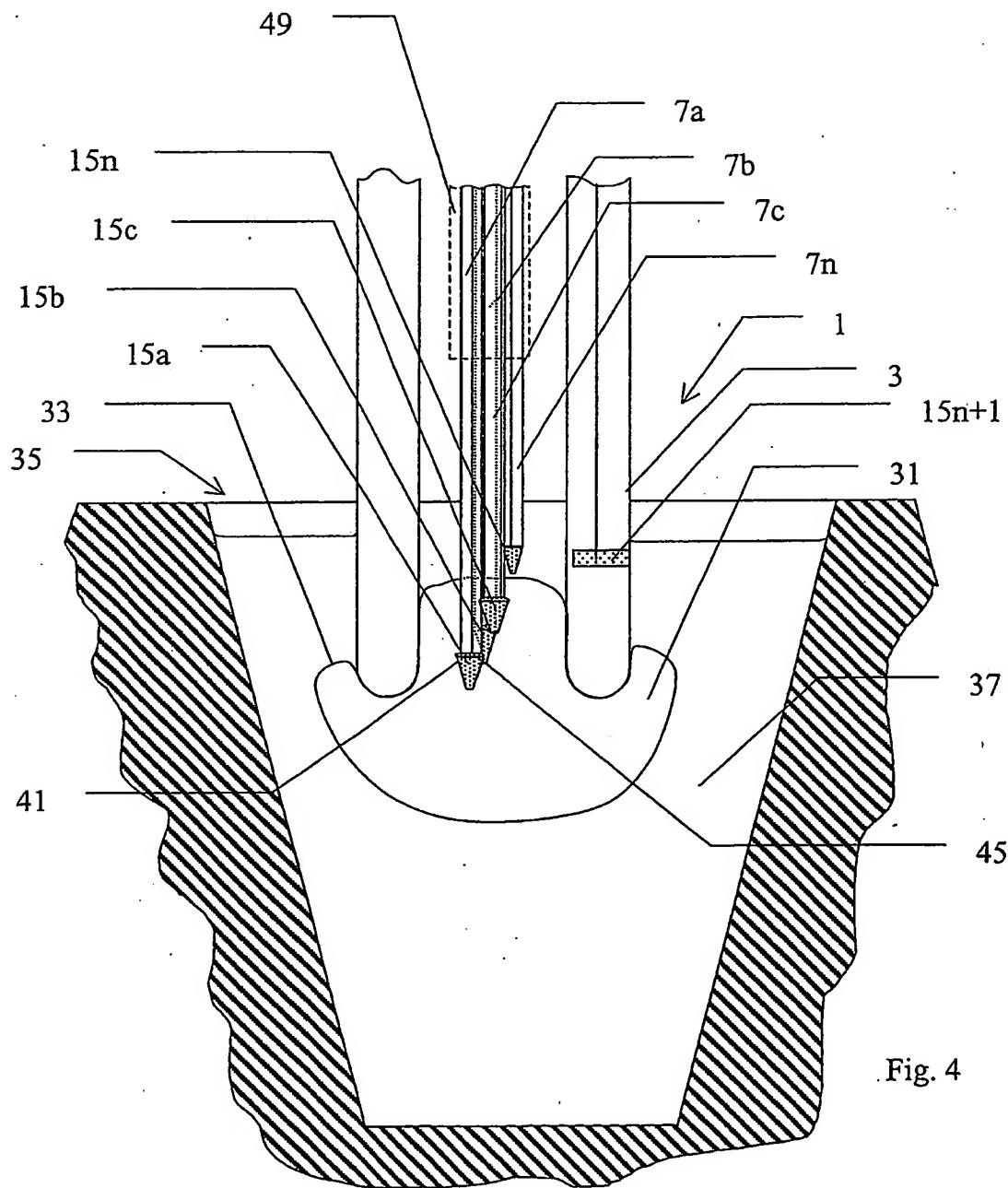


Fig. 4

Fig. 5

